



ontario hydro
research division

To Mr. F.J. Kee
Director of Research

RESPONSES OF GIZZARD SHAD (*DOROSOMA CEPEDIANUM*)
TO DIFFERENT FLASH CHARACTERISTICS OF STROBE LIGHT

P.H. Patrick

The responses of gizzard shad (*Dorosoma cepedianum*) to various discharge curves of strobe light were investigated under laboratory conditions. Flash characteristics such as rise time and peak duration appear critical in eliciting a fish avoidance response. With increased duration of light flash there is less of a fish avoidance response. A blue filtered strobe, transmitting primarily blue-green light, appears less effective as a fish repellent compared to that of a yellow filtered (yellow, orange, red light) strobe and white strobe (all visible light).

INTRODUCTION

Both laboratory and field research has indicated the potential of using strobe light alone or as part of a fish exclusion scheme (OHRDR 81-61-K, 81-190-K, 82-165-K). Although fish show an avoidance of this light source, the actual reasons or mechanisms involved in eliciting this response are only partly known. Avoidance appears only partly related to light intensities (OHRDR 79-104-K, 81-190-K), and probably unrelated to the spectral composition of the strobe light source (OHRDR 82-476-K). Flash rate appears to be important, however, with noticeable avoidance occurring when frequency exceeds 200 flashes/minute (OHRDR 79-104-K, 82-476-K). Still, other light sources such as incandescent and metal halide, when flashed at 200/minute and higher, are generally ineffective as fish repellants (OHRDR 82-476-K). These light sources differ mainly from strobe in that the duration of each flash is considerably longer. It is possible that fish avoidance of strobe light may be related to its short flash duration. To test this hypothesis, a study was initiated to determine the responses of fish to different strobe discharge curves of varying durations.

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MATERIALS AND METHODS

1. Species Investigated

Adult shad, ranging in size from 25 to 40 cm, were used as test species. Fish were collected by electro-fishing techniques in the winter of 1981 at both Pickering GS and Bruce GS. Prior to experimentation, fish were held in either 2.4 or 3.6 m circular pools under a controlled photoperiod of 10-14 h of light. Water temperatures ranged from approximately 7.0 to 9.5°C throughout the testing period.

2. Types of Discharge Curves

Four different discharge curves of varying rise times and peak durations were produced by changing the inductance and capacitance of the strobe (Figure 1, Table 1). These modifications and curve-values are based on preliminary work conducted by Electrical Research (OHRDR E81-75-H). Flash characteristics were measured using an oscilloscope (Phillips Model PM322) in conjunction with a photocell. With increased capacitance and inductance, the shape of the strobe discharge changed significantly, as both rise times and peak durations were altered. Rise time, defined as the time period (ms) required to achieve peak output (measured between 10-90% of peak output) ranged from 0.12 ms for curve B to 3.0 ms for curve E, the latter being approximately 43 times slower than that of a normal strobe discharge. Peak duration, or duration of highest output (measured at 95% of peak output) ranged from 0.20 ms for curve B to 4.0 ms for curve E. These peak durations were at least one order of magnitude longer than that of a normal strobe flash (curve A). Differences in total duration between normal and modified discharge curves were less obvious, with discharge curve E only 2.5 times longer than the normal strobe. Curves B and C were similar in total duration to the normal strobe (Curve A).

TABLE 1

CAPACITANCE AND INDUCTANCE MODIFICATIONS
TO STROBE LIGHT

<u>Modification</u>	<u>Inductance (mH)</u>	<u>Capacitance (μF)</u>	<u>Area Under Curve (V.ms)</u>
Curve			
A Normal	0.0	40	.355
B	9.3	40	.351*
C	8.3	40	.364
D	65	40	.361*
E	8.3	1000	.360*

* Intensity or area under the curve has been adjusted for curves B, D, and E. by using clear filters, and by slight adjustment of strobe's position in the experimental chambers.

An increase in inductance and capacitance to the strobe unit resulted in a reduced flash rate, with a maximum rate of only 150 flashes/minute achieved for curves D and E. All other curves (including normal discharge) were adjusted to this flash rate. Based on preliminary observations and earlier work (OHRDR 79-104-K), this flash rate was probably at or near the minimum level at which fish elicited marked avoidance.

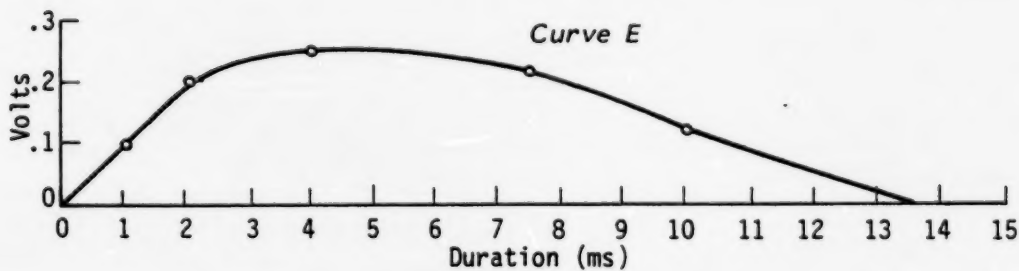
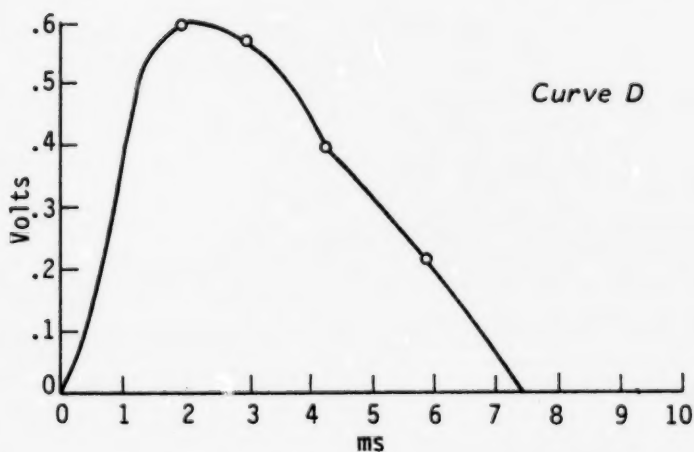
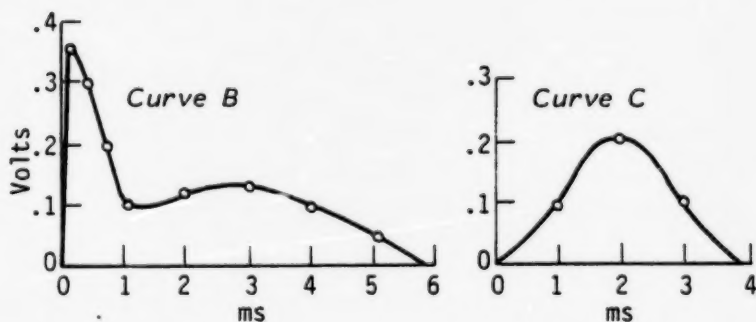
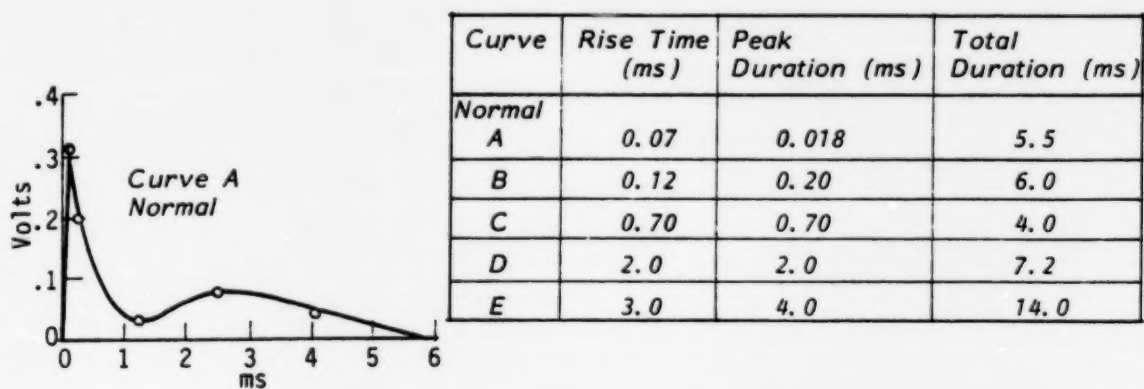


FIGURE 1
VARIOUS DISCHARGE CURVES OF STROBE LIGHT USED IN
EXPERIMENTAL DESIGN

Spectral compositions for each modified discharge curve varied slightly from that of the normal strobe (Figure 2). Generally light was transmitted throughout the entire visible range, with slightly higher energy output in the orange and red regions of the spectrum (especially curves B and C). Because of an increased orange-red content of the discharge, increased fish avoidance could be expected for these discharge curves (OHRDR 78-516-K).

3. Chambered Experiments

Both short (5, 15 minutes) and long (12 h) term experiments were used to determine the responses of gizzard shad to various discharge curves produced by strobe light. All experiments were conducted in a 2.4 m diameter circular tank which was divided equally into three areas, each approximately 1.5 m² (Figure 3). In the design, one chamber was illuminated with strobe source, which was the sole source of illumination during the testing period. For each experiment, the strobe light source (modified or normal) was projected downwards in the tank producing concentric zones of varying light intensities. Light output in curves B, D and E were higher than that of the normal strobe (Figure 1, area under curve), and had to be adjusted using clear plexiglass filters, and by slight adjustment of the strobe's position in the experimental chamber. These filters had no noticeable effect on the spectral output of the strobe. Intensity, measured as area under each discharge curve, varied less than 10% among all discharge curves (Table 1). Strobe light intensities, for all discharge curves ($\pm 10\%$) ranged from approximately 333 lux (7.4 $\mu\text{E}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) near the light source to approximately 13 lux (0.3 $\mu\text{E}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) at the edge of the light zone. Light recorded near the outer wall was approximately 2.0 lux ($< 0.1 \mu\text{E}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$). The illuminated chamber had no influence on the other two chambers which were in darkness during the testing period.

In the long term tests, closed circuit T.V. was used to monitor fish numbers in the lighted chamber (for each discharge curve) at 10 minute intervals (freeze frame) over the 12 hour monitoring period. One replicate (n = 15 fish) was performed for each discharge curve (except curve E)*. The number of shad that entered the same experimental chamber (strobe source off) over a similar 12 h period under low level light (< 3 lux, $< 0.01 \mu\text{E}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$), served as a control.

Short term tests consisted of monitoring fish numbers and distribution in the lighted chamber following both 5 and 15 minute illumination periods. Ten replicates (n = 15 fish/replicate) were performed for both modified and normal discharge curves (total 80 replicates). After each selected time period, chutes which divided the chambers were closed and the number of shad in each chamber recorded.

* Because of technical difficulties, modified curve E could not produce light for more than a 30 minute period.

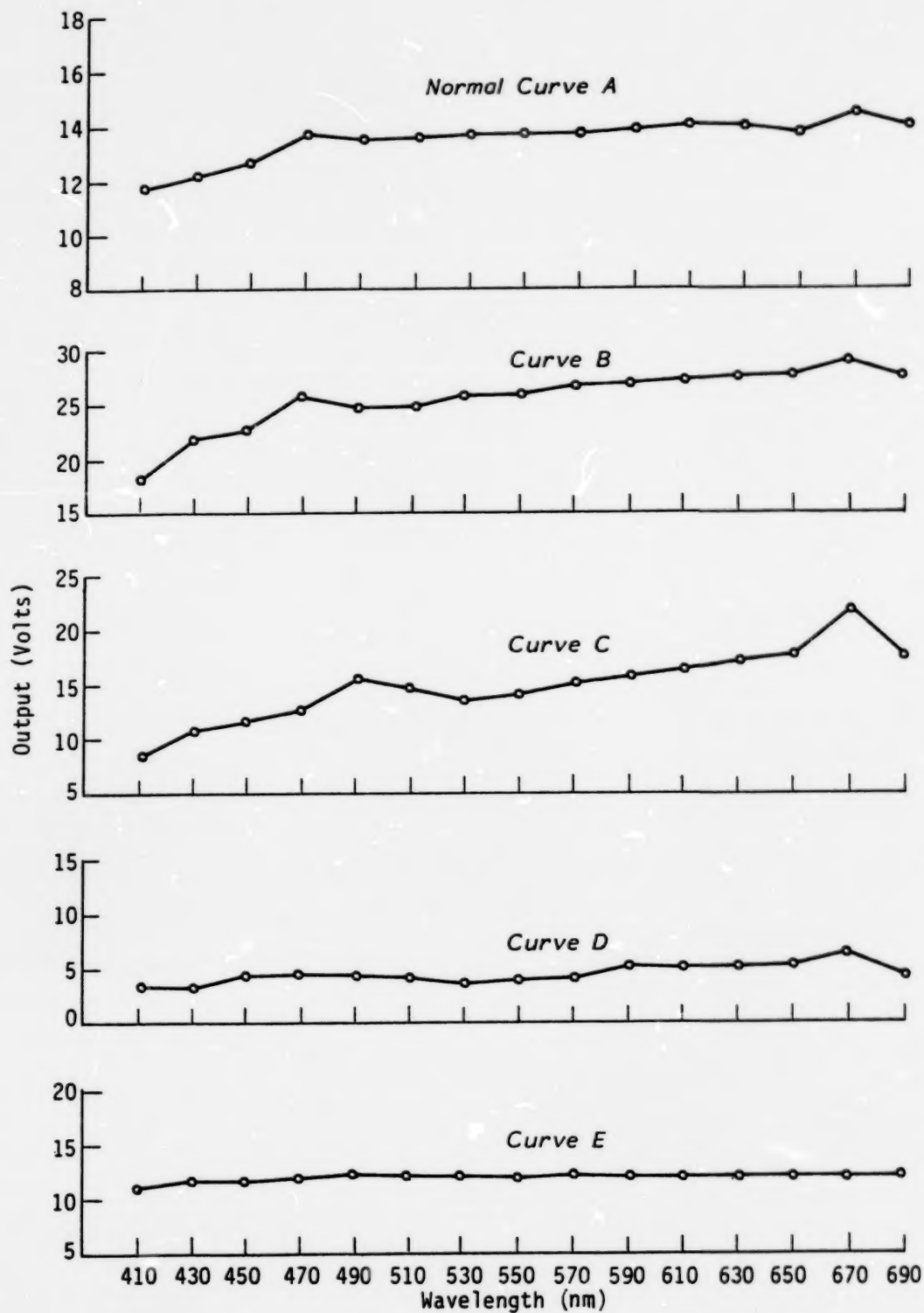


FIGURE 2
SPECTRAL COMPOSITION OF VARIOUS DISCHARGE
CURVES OF STROBE LIGHTS (C.C.I.W. - QUANTUM METER 3500)

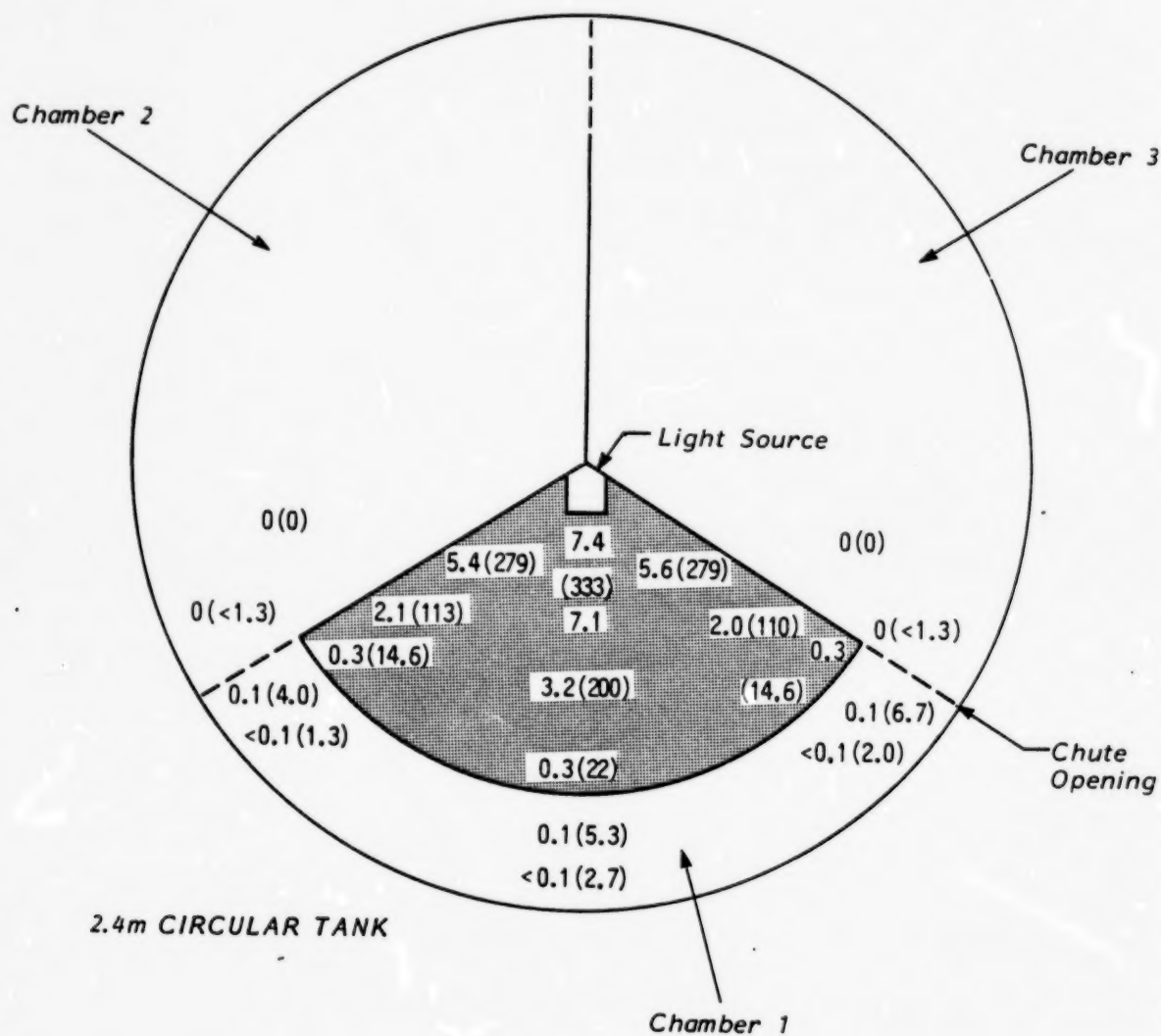


FIGURE 3
LIGHT INTENSITIES MEASURED AS ILLUMINANCE
(LUX, IN BRACKET) AND QUANTUM FLUX ($\mu E \cdot m^{-2} \cdot s^{-1}$)
FOUND IN EXPERIMENTAL CHAMBER

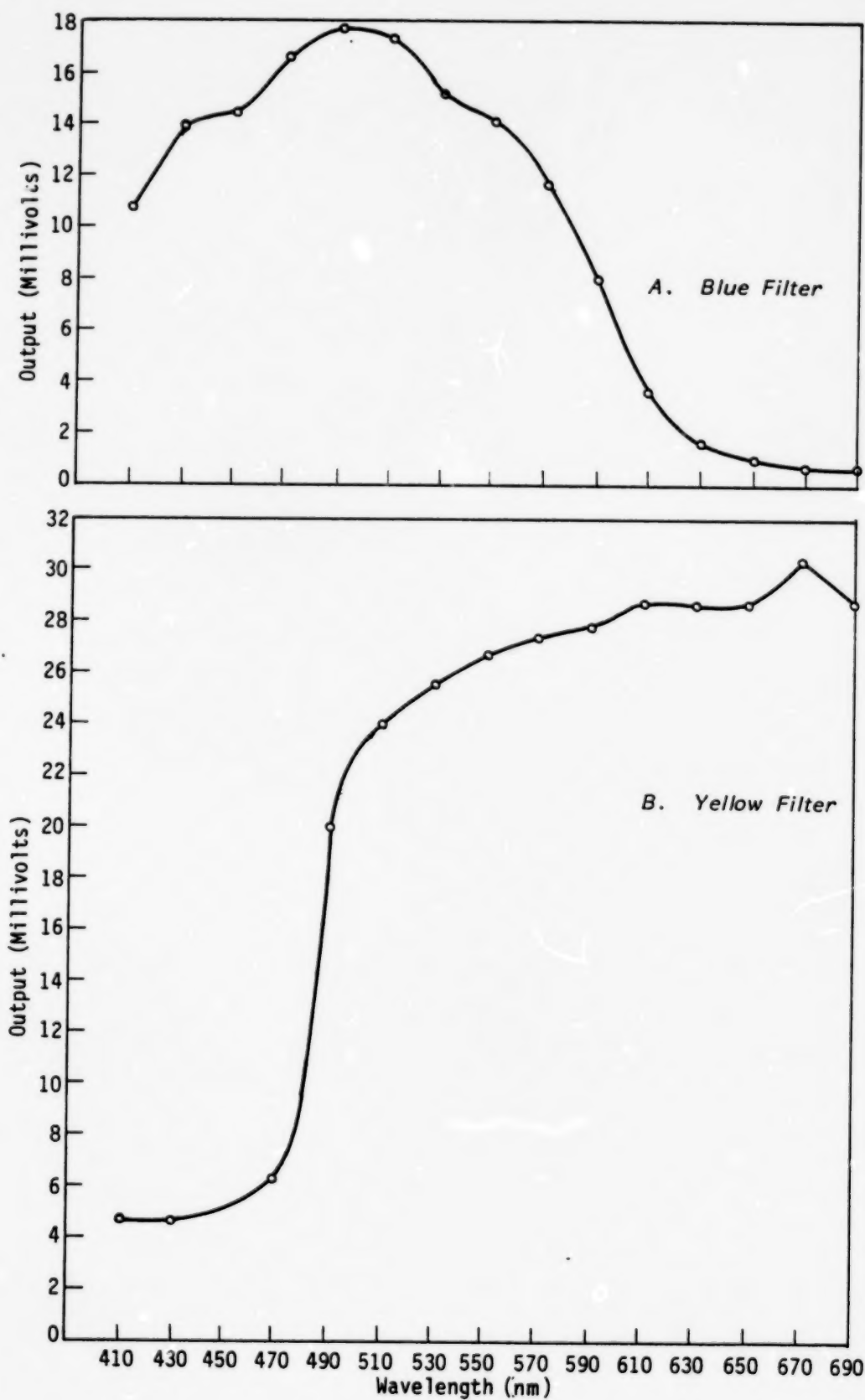


FIGURE 4
SPECTRAL COMPOSITION OF A, BLUE AND B, YELLOW
FILTERED STROBE LIGHT SOURCES (C.C.I.W. QUANTUM
METER 3500)

158044 RD

Observations were also made on the distribution of shad within each chamber relative to the light source after closing the chutes. Ten control tests (15 fish/replicate) were also performed for each experimental condition (total 80 replicates) in complete darkness to assess fish numbers in each chamber in the absence of strobe light. Control and experimental tests were alternated to reduce any temporal bias.

Additional tests were also conducted to determine the responses of shad to a normal strobe light source covered with blue or yellow filters. The blue filter transmitted light primarily in the 410 and 630 nm visible range, with maxima occurring in the blue-green region (450-530 nm, Figure 4). The yellow filter transmitted all visible light beyond 470 nm, with highest output in the yellow (577-597 nm), orange (597-622 nm) and red (622-690) regions of the visible spectrum. Experimental procedure was similar to that described above for short term (5 and 15 min) tests.

RESULTS AND DISCUSSION

1. Response of Shad to Various Strobe Discharge Curves

In the long term tests (12 h), an increase in the number of shad in the lit chamber occurred with an increase in peak duration of the flash (Figure 5). Statistically, the lowest number of fish was observed in the chamber lit with a normal strobe (curve A) or with discharge curve B, indicating that shad showed strongest avoidance of these light sources over the monitoring period ($F_{4,360} = 195$, $p < 0.05$, Appendix C). The number of shad observed in the chamber lit with discharge curves C and D over the 12 h monitoring period are not significantly different from the control test (Multiple Range Test, Appendix C). There was no noticeable evidence of a change in fish numbers in the experimental chamber over a 12 h monitoring period for either normal or modified discharge curves (Figure 6). Generally, there appeared to be fewer fish observed as the monitoring period progressed, suggesting a slight avoidance of the lit area for all discharge curves.

Although discharge curve B (rise time 0.12 ms, peak duration 0.20 ms) appeared similar in effectiveness to the normal strobe in excluding shad (averaged over a 12 h period, Figure 5), this avoidance response was not evident in the initial 5 and 15 minutes of experimentation (Figure 7). During these illumination periods, the lowest mean number of shad was consistently recorded only for the normal strobe discharge curve (Table 2, Multiple Range Test). Relative to control tests, fewest shad numbers were observed in the chamber lit with normal strobe (curve A) and discharge curve C in the 5 minute tests, and only with the normal strobe following 15 minutes of illumination (Figure 7, Table 3).

These results indicate that strobe flash duration is critical in eliciting an initial fish avoidance response. Distribution of fish in the lighted chamber following 5 and 15 minute illumination periods supplemented these data. Fish were frequently observed near the light source in all modified curve tests, whereas they were generally located near the edge of the tank where intensities were lowest in the normal strobe tests.

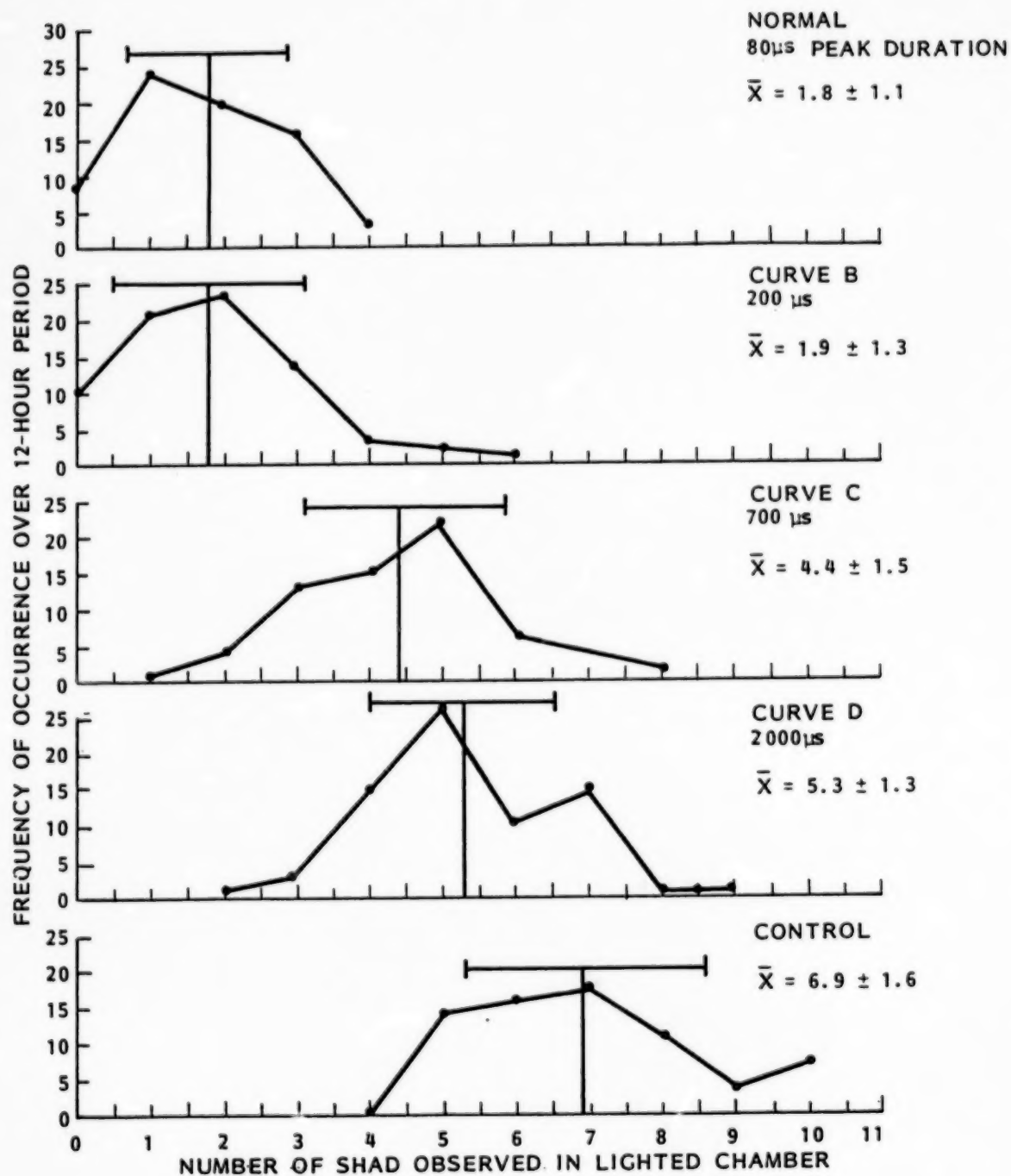


FIGURE 5
FREQUENCY OF SHAD OBSERVED IN EXPERIMENTAL LIT ZONE
OVER A 12-HOUR PERIOD

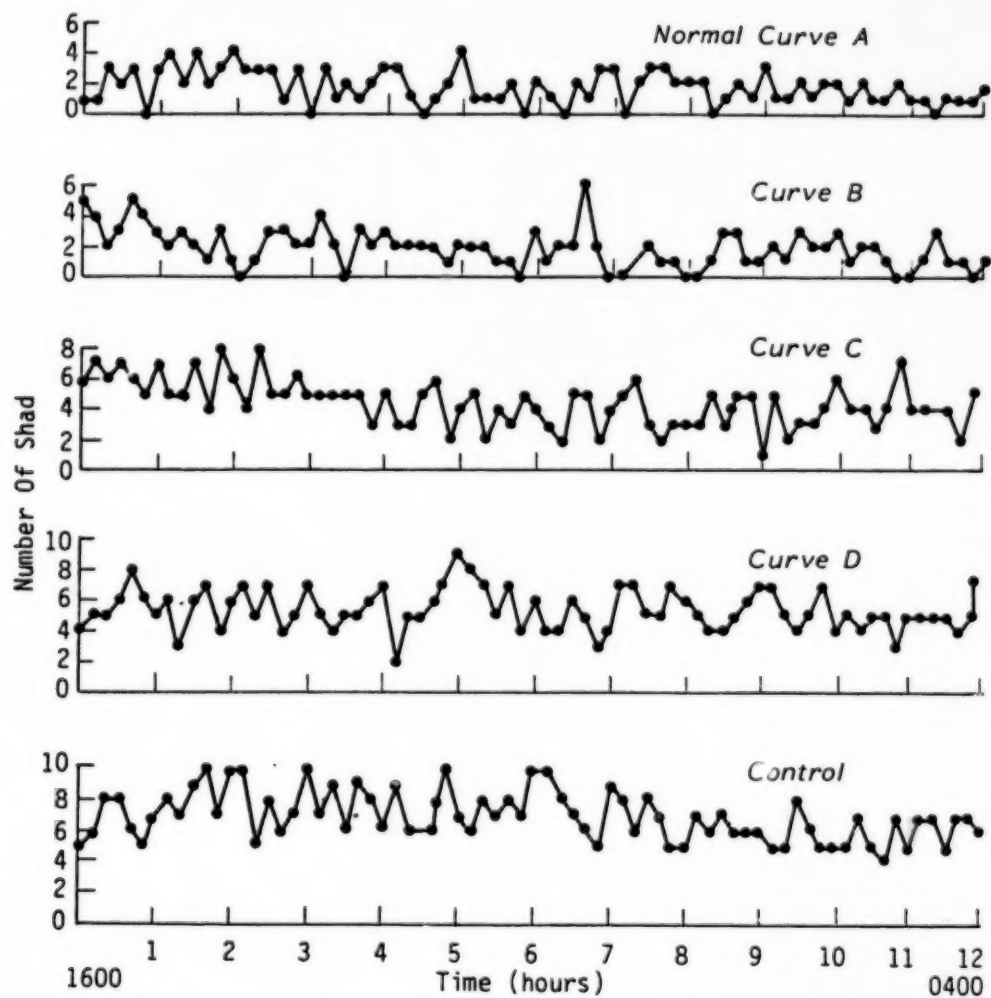


FIGURE 6
NUMBER OF SHAD RECORDED IN EXPERIMENTAL CHAMBER

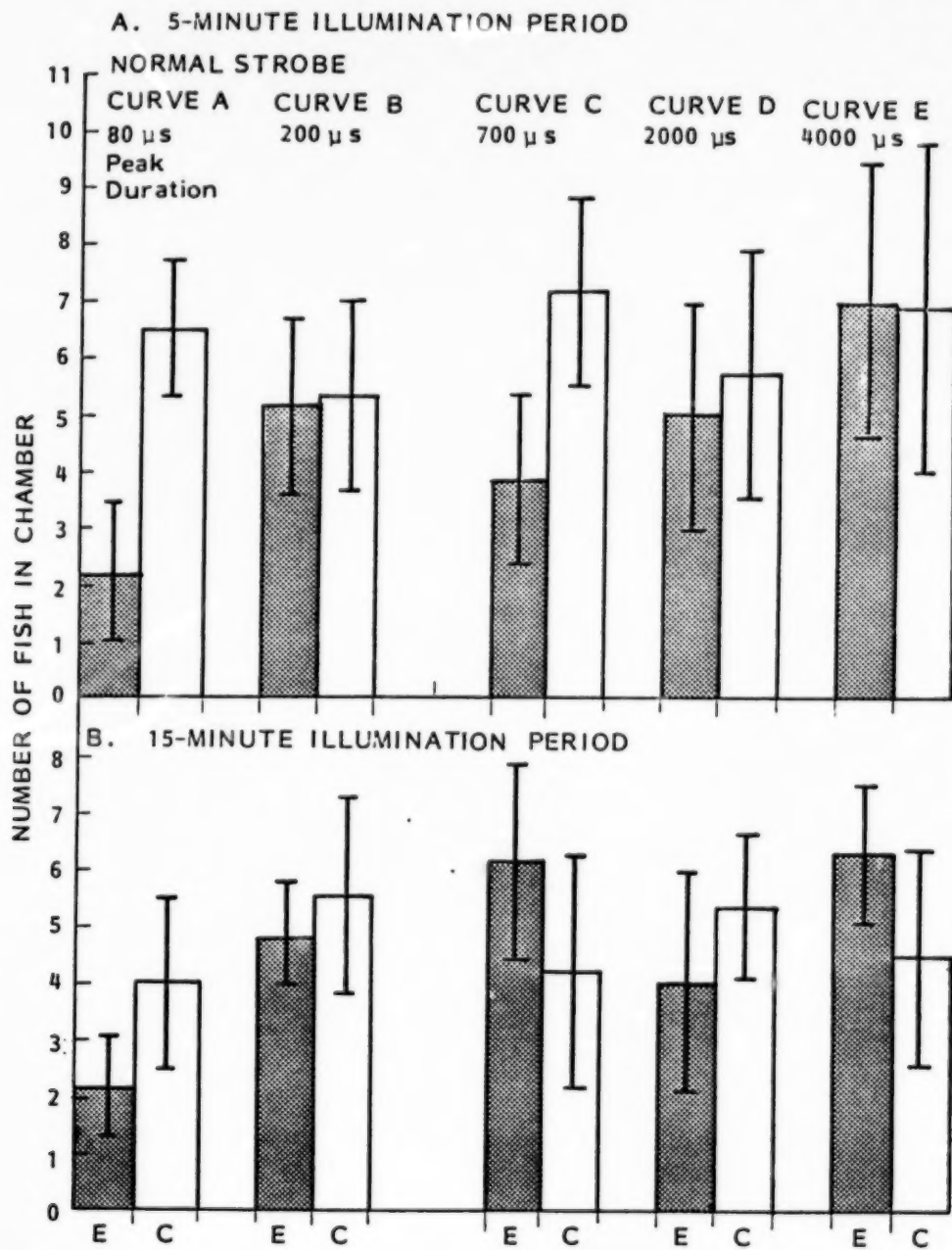


FIGURE 7
RESPONSES OF GIZZARD SHAD TO
VARIOUS STROBE DISCHARGE CURVES
(E = EXPERIMENTAL, C = CONTROL)

TABLE 2

STATISTICAL COMPARISON OF SHAD NUMBERS RECORDED IN EXPERIMENTAL CHAMBER LIT WITH VARIOUS STROBE DISCHARGES

Illumination Period (min)	F-statistic		Multiple Range (S.N.K.) lowest + highest numbers
	d.f.	F	
5	4,45	8.2*	Discharge Curves normal C D B E (A)
15	4,45	14.0*	Discharge Curves normal D C B E (A)

P<0.05

TABLE 3

STATISTICAL COMPARISON (t-VALUES) OF SHAD NUMBERS RECORDED IN EXPERIMENTAL LIT CHAMBER RELATIVE TO CONTROL TESTS (Figure 7)

Illumination Period (min)	A (Normal)	B	Discharge Curve		
			C	D	E
5	4.9* (avoidance)	0.2	3.7* (avoidance)	0.8	0.2
15	2.6* (avoidance)	1.0	2.8* (attraction)	1.9	3.4* (attraction)

2. Shad Response to Blue and Yellow Filtered Strobes

Shad showed an initial attraction to blue filtered strobe light (after 5 minutes, Table 4). Mean shad numbers observed in the experimental lit chamber were significantly higher than that observed in control tests. In one replicate 13 of 15 fish (or 86% of total) was observed in the lighted chamber (Appendix A). However, following 15 minutes of illumination, there was a reduction in the number of shad recorded in the experimental lit chamber, suggesting a delayed avoidance response (Table 4).

TABLE 4
COMPARISON OF MEAN SHAD NUMBERS RECORDED
IN EXPERIMENTAL LIT CHAMBER RELATIVE TO CONTROL TESTS

Illumination Period (min)	BLUE FILTER					YELLOW FILTER				
	Control X	S.D. (X)	Experimental X	S.D. (X)	Response	Control X	S.D. (X)	Experimental X	S.D. (X)	Response
5	5.3	0.9	7.3*	2.5	Attraction	3.1	1.6	4.4	1.9	-
15	6.0	1.2	4.3*	1.9	avoidance	4.3	2.4	2.2*	1.7	avoidance

* $p < 0.05$

In the yellow filtered 5 minute strobe tests, there was no significant difference between shad numbers recorded between experimental and control tests, indicating neither attraction nor avoidance (Table 4). However, similar to the blue filtered strobe results, an avoidance was observed with prolonged illumination (15 minutes).

3. Effect of Strobe Flash Duration on Shad Behaviour

Flash duration appears to significantly influence shad behaviour with less of an avoidance response occurring with increased flash duration. These results confirm the speculation that fish avoidance of strobe light may be related to the flash characteristics of the strobe (OHRDR 82-476-K). However, it should be emphasized that rise time and peak duration are probably more critical than the total duration of the flash in eliciting this avoidance. Although curves B and C had similar total durations as the normal strobe (curve A), they were relatively ineffective as a fish repellent (Figures 1,7). Flashing light of short peak duration such as that produced by a normal strobe ($<100\mu s$) is foreign to most fresh-water pelagic species, and generally results in disorientation, confusion and avoidance (as observed under

laboratory conditions). In marine environments, several organisms (algae, vertebrates, fish) have evolved the ability (bioluminescence) to repel (or escape from) potential predators, by emitting light of short duration (Herring 1978, Morin 1982, pers comm). It is noteworthy that the shape of the flash produced by these organisms (ie rapid rise time, slow exponential decay) is almost identical to the discharge curve of strobe light (although the total duration is much longer).

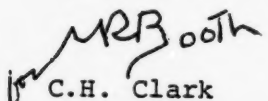
In addition to flash duration, flash rate has also consistently been found to be important in eliciting a fish avoidance response (OHRDR 79-104-K, OHRDR 82-476-K). The flash rate used in these tests (150 flashes/min) is probably the minimum at which avoidance will occur. For field applications a slightly higher rate would be recommended (200-250 flashes/minute).

Experiments with filtered strobe light have shown that if the blue-green content of the emissions is increased there is evidence suggesting an attraction (at least initially). Attraction by fish to these wavelengths tends to override their avoidance of a rapid flash. This can have important implications in field situations where blue-green light penetrates far in the water column, since a far field attraction to a strobe light source may potentially exist when unfiltered light sources are used. However, as fish move closer to the light source, and other wavelengths become apparent, an avoidance response should occur. It is expected that spectral composition of a strobe probably plays a limited role in repelling fish.

SUMMARY

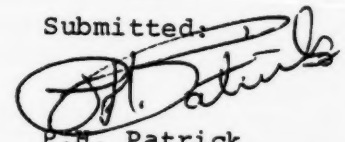
1. Flash characteristics of strobe light such as rise time and peak duration appear critical in eliciting a fish avoidance response.
2. With an increase in duration of light flash, there is less of a fish avoidance response.
3. A blue-filtered strobe light appears less effective as a fish repellent compared to that of yellow (filtered) and white strobes.

Approved:


C.H. Clark
Manager
Chemical Research Dept

PHP:kwk

Submitted:


P.H. Patrick
Research Biologist
Biological Research Section

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9. OHRDR E81-75-H, Extending the flash duration of strobes, M. Staelter.

APPENDIX A

NUMBER OF GIZZARD SHAD RECORDED IN EXPERIMENTAL AND CONTROL CHAMBERS IN 5 AND 15 MINUTE TESTS

Type	Time (min)	Replicate											
			1	2	3	4	5	6	7	8	9	10	
A Normal Strobe	5	Control	Chamber 1	6	6	7	6	6	7	6	4	8	9
			Chamber 2	4	3	2	3	1	2	2	2	1	1
			Chamber 3	5	6	6	6	8	6	7	9	6	5
		Exp	*1	4	3	3	1	1	1	4	1	3	1
			2	6	9	3	7	4	4	5	6	3	6
			3	6	3	9	7	10	10	6	8	9	8
A Normal Strobe	15	Control	1	2	3	3	6	5	7	3	3	4	4
			2	5	5	5	5	5	6	6	6	4	4
			3	8	7	7	4	5	3	7	6	7	7
		Exp	*1	4	2	1	2	3	2	2	1	3	2
			2	3	9	5	9	6	5	3	5	5	7
			3	8	4	9	4	6	8	10	9	7	6
B	5	Control	1	7	4	7	6	7	5	7	2	5	3
			2	2	5	6	6	4	5	3	5	3	9
			3	6	6	2	3	4	5	5	8	7	3
		Exp	*1	6	4	5	3	3	7	8	4	6	5
			2	2	5	3	3	5	5	4	5	2	4
			3	7	6	7	9	7	3	3	6	7	6
B	15	Control	1	4	4	5	8	3	7	7	4	6	7
			2	4	5	3	4	1	2	2	3	6	3
			3	7	6	7	3	11	6	6	8	3	5
		Exp	*1	4	4	5	5	4	5	7	5	5	4
			2	5	5	3	3	3	2	4	4	6	5
			3	6	6	7	7	8	8	4	6	4	6
C	5	Control	1	9	10	7	5	7	9	6	5	7	6
			2	1	1	2	4	1	2	4	4	2	5
			3	5	4	6	6	7	4	5	6	6	4
		Exp	*1	6	6	4	3	2	5	5	3	2	2
			2	4	3	9	8	4	6	4	4	4	7
			3	5	6	2	4	9	4	6	8	9	6
C	15	Control	1	7	5	2	4	5	2	8	2	3	4
			2	4	5	4	5	4	8	3	4	5	7
			3	4	5	9	6	6	5	4	9	7	4
		Exp	*1	5	6	10	4	5	6	5	6	8	6
			2	8	5	4	7	8	6	6	4	5	4
			3	2	4	1	4	2	3	4	5	2	5

* Chamber 1 lit in experimental

Type	Time (min)		1	2	3	4	5	6	7	8	9	10		
D	5	Control	Chamber 1	3	9	3	5	3	5	8	5	8	7	extra
		Chamber 2	6	2	8	6	6	6	4	3	3	4		
		Chamber 3	6	4	4	4	6	4	3	7	4	4		
		Exp	* 1	2	7	3	5	8	5	4	3	4	8	
			2	6	6	7	3	4	7	6	6	6	4	
			3	7	2	5	7	3	3	4	6	5	3	
D	15	Control	1	5	7	7	4	-	4	4	5	7	6	5
		2	8	6	6	6	-	3	8	4	3	6	7	
		3	2	2	2	5	-	8	3	6	5	3	3	
		Exp	* 1	7	6	2	6	-	4	3	2	3	2	4
			2	1	7	8	4	-	4	5	8	5	5	5
			3	7	2	5	5	-	7	7	5	7	8	6
E	5	Control	1	6	8	6	8	6	9	12	2	5	4	
		2	3	4	3	2	3	2	1	10	7	5		
		3	6	3	6	5	6	4	2	3	3	6		
		Exp	* 1	11	5	5	7	9	6	5	9	8	3	
			2	2	5	2	5	3	5	5	3	4	6	
			3	2	5	8	3	3	4	5	3	3	6	
E	15	Control	1	4	2	6	4	5	6	3	2	3	4	
		2	5	6	5	7	7	5	6	6	6	4		
		3	6	7	4	4	3	4	6	7	6	7		
		Exp	* 1	4	7	5	6	7	5	7	8	7	6	
			2	8	4	5	5	6	5	4	2	7	2	
			3	3	4	5	4	2	5	4	5	1	7	
F (yellow) filter	5	Control	1	2	4	1	1	3	5	5	5	3	2	
		2	5	6	6	3	3	4	6	4	8	7		
		3	8	5	8	11	9	6	4	6	4	6		
		Exp	* 1	2	3	5	3	5	7	3	8	3	5	
			2	3	5	7	6	6	4	6	3	8	7	
			3	10	7	3	6	4	4	6	4	4	3	
F (yellow) filter	15	Control	1	8	5	1	2	3	3	8	6	3	4	
		2	2	3	9	5	5	2	2	3	5	4		
		3	5	7	5	8	7	10	5	6	7	7		
		Exp	* 1	3	0	1	0	3	3	5	4	1	2	
			2	2	4	5	4	7	3	6	4	3	6	
			3	10	11	9	11	5	9	4	7	11	7	

Type	Time (min)		Replicate										
			1	2	3	4	5	6	7	8	9	10	
G (Blue)	5	Control Chamber	1	6	5	4	7	5	6	5	5	6	4
			2	5	6	5	4	6	7	6	5	6	4
			3	4	4	6	4	1	2	4	5	5	6
		Exp	*1	3	7	7	8	8	13	6	7	6	8
			2	7	4	3	6	4	2	6	4	5	3
			3	5	4	5	1	3	0	3	4	4	4
G	15	Control	1	7	6	8	5	7	4	5	6	7	5
			2	8	7	6	10	6	7	8	6	8	3
			3	0	2	1	0	2	4	2	3	0	7
		Exp	*1	6	1	2	4	3	4	5	5	7	6
			2	9	7	9	4	7	7	7	6	5	4
			3	0	7	4	7	5	4	3	4	3	5

APPENDIX B

NUMBER OF SHAD RECORDED IN EXPERIMENTAL CHAMBER FOR EACH DISCHARGE CURVE OVER A 12 h PERIOD

Time (min)	Control		Number		B		C		D	
	lst	6 hr	2nd	6 hr	lst	6 hr	2nd	6 hr	lst	6 hr
0	5	-	0	-	5	-	5	-	4	-
10	6	10	1	1	4	2	7	2	5	4
20	8	8	3	0	2	2	6	5	5	6
30	8	7	2	1	3	6	7	5	6	5
40	6	6	3	3	5	2	6	2	8	3
50	5	5	0	0	4	0	5	4	6	4
100	7	9	3	3	3	0	7	5	5	7
10	8	8	4	1	2	1	5	6	6	7
20	7	6	2	2	3	2	5	3	3	5
30	9	8	4	3	2	1	7	2	6	5
40	10	7	2	3	1	1	4	3	7	7
50	7	5	3	2	3	0	8	3	4	6
200	10	5	4	2	1	0	6	3	6	5
10	10	7	3	2	0	1	4	5	7	4
20	5	6	3	0	1	3	8	3	5	4
30	8	7	3	1	3	3	5	5	7	4
40	6	6	1	2	3	1	5	5	4	5
50	7	6	3	1	2	1	6	1	7	7
300	10	6	0	3	2	2	5	5	5	7
10	7	5	3	1	4	2	5	2	4	5
20	9	5	1	1	2	3	5	3	4	4
30	6	8	2	2	0	2	5	4	5	5
40	9	6	1	1	3	2	6	3	7	7
50	8	5	2	2	2	4	5	4	5	4
400	6	6	2	2	3	0	3	6	6	4
10	9	5	3	2	2	2	5	4	7	5
20	6	7	3	1	3	2	3	4	2	4
30	6	5	1	2	2	2	3	3	5	5
40	6	4	0	1	2	0	6	7	6	3
50	10	7	1	1	1	0	2	4	7	5
500	7	5	2	2	1	0	4	4	9	5
10	6	7	4	1	2	1	4	4	8	5
20	6	7	1	1	2	1	4	4	7	5
30	8	7	1	0	2	1	2	4	5	5
40	7	5	1	1	2	1	4	4	4	4
50	7	7	1	1	2	1	2	2	5	4
600	10	6	2	2	3	0	4	3	6	7

APPENDIX C

ANOVA COMPARISON OF MEAN NUMBER OF SHAD RECORDED IN LIGHTED CHAMBER OVER A 12 h MONITORING PERIOD FOR VARIOUS STROBE DISCHARGE CURVES

Analysis of Variance

Source	Sum of Squares	Degrees Of Freedom	Mean Square	F-Ratio	Significance Probability
Mean	6001.10	1	6001.0959	3187.84	.0000
Groups	1467.21	4	366.8014	194.85	.0000
Within Groups	677.70	360	1.8825		
Total	8146.00	365			

MULTIPLE RANGE (S.N.K.)

Normal	Curve B	Curve C	Curve D	Control
1.8	1.9	4.4	5.3	6.9